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Potential of Air-Propelled Abrasives for Selective Weed Control

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Novel forms of selective weed control are needed by many types of growers, but especially by organic growers who are restricted from using synthetic herbicides. Abrasive grit made from corn cobs was expelled from a sand blaster at 517 kPa pressure and aimed at plants of common lambsquarters and corn positioned 300 mm distant. Most small weed plants were killed by one split-second blast of grit, but corn plants suffered little damage by the same treatment. Air-propelled grit made from agricultural residues possibly could be used for selective nonchemical weed control without the need for soil tillage.

Nomenclature: Common lambsquarters, *Chenopodium album* L.; corn, *Zea mays* L.

Key words: Grit, organic control, nonchemical control, physical control, sand blaster.

Organic crop managers often rely heavily upon soil tillage as a substitute for herbicides, although several other tactics also can be employed (e.g., crop rotation, cover crops). These tactics have been reviewed often in recent years (e.g., Cloutier et al. 2007; Van Der Weide et al. 2008). Regardless of the availability of these tactics, weeds remain a persistent issue for crop management without herbicides. Moreover, soil tillage, for whatever reason, remains a management tactic that likely is not sustainable for soil and environmental health when viewed over the long term. Consequently, an impetus exists for weed researchers and others to devise new management tactics that do not involve soil tillage, thereby alleviating concerns with regard to soil degradation, and that do not depend upon synthetic herbicides, thus appeasing the philosophies of organic advocates. Weed control through flaming, steaming, allelopathy, mycoherbicides, classical biological control, among others, may meet both of these aforementioned criteria, but none of these tactics has been particularly successful in agronomic crops.

A recently conceived tactic involves the use of a sand blaster for POST weed control. This technique is unlike the Pneumat system (Lütkemeyer 2000; Sørensen et al. 2007), which uses subsoil nozzles to blow compressed air upward to dislodge the roots of weeds. Instead, a sand blaster uses grit as abrasive particles, propelled from nozzles above the soil surface, to shred and kill plants. As far as is known, Nørremark et al. (2006) were the first to conceive of this idea, but they did not test it experimentally. Simple greenhouse experiments indicated that agricultural residues can be used as grit and that the technique has potential to control small weeds at air pressures and delivery rates within the realm of practicality for agriculture (F. Forcella, unpublished data). Results from the initial experiments implied that crop/weed selectivity may be possible because large weeds were not controlled as easily as small weeds. The objective of the current study was to demonstrate such selectivity using common lambsquarters and corn as model weed and crop plants in a greenhouse setting.

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Materials and Methods

Weeds and Growing Conditions. Seeds of a representative, small-seeded, broad-leaved weed, common lambsquarters, were sown in 0.5-L pots (90 by 90 mm surface) and placed in a greenhouse set at 25/15 C day/night temperatures. The greenhouse was located in Morris, MN, at a latitude 45° 41′ N, and longitude of 95° 48′ W. The source of the common lambsquarters seed was from within 10 km of this location. Pots were filled with 0.45 L of soil, which consisted of a 1 : 1 : 1 mixture of coarse sand, peat, and loam. Plants were thinned to 1 plant/pot and allowed to grow to various developmental stages before treatment with the sand blaster. Pots were watered daily and fertilized weekly with a commercially available, complete-nutrient solution. Plants were exposed to natural day lengths (April through June), with midday light intensities between 400 to 800 μE m^{-2} s^{-1}.

The same experiment was repeated in two trials, May 10, 2008, using 68 plants, and June 1, 2008, using 123 plants. Leaf-growth stages were scored, and heights of all plants were measured immediately before treatment. Stages and heights ranged from cotyledon to eight leaves and 5 to 56 mm in trial 1, and from cotyledon to 10 leaves and 5 to 85 mm in trial 2. Plants were subjected to split-second blasts from a sand blaster (described below) until they were judged to have been killed, and the number of blasts necessary for this judgment was recorded. Small plants (one to three leaf-growth stages) typically were obliterated with a single split-second blast, and the judgment of death was obvious. Larger plants (4 to 10 leaf-growth stage) often required additional blasts before death was assumed to have occurred. To guard against poor judgment, after treatment with the sand blaster, pots were arranged randomly in trays and allowed to grow for 1 wk. Of the 191 plants so treated, only three resumed weak growth, and these were the three largest plants treated in the experiments: two at the eight-leaf stage from the first trial, and one at the 10-leaf stage from the second trial.

Data were categorized and converted to frequencies. Final categories were three development stages at time of treatment: 0–1 leaf (cotyledon to one visible true leaf), 2–3 leaf (two to three visible leaves), and 4–10 leaf (4 to 10 visible leaves). Frequencies at which plants in these three stages were killed by one, two, three, and four or more blasts were calculated for

Figure 1. Blasting unit with air and grit intake hoses, trigger to activate air pressure, and nozzle from which air-propelled grit is discharged.

both trials. Distributions for the two trials were compared using the Kolmogorov–Smirnov test and its associated K–S statistic (Statistix 8 software package[1]).

Sand Blaster and Grit. The small unit (Figure 1) used in experiments is available commercially[2] as a cabinet blaster. Grit from the cob (rachis) of corn ears was used in all experiments. Grit is available in differing sizes, but 20/40 mesh grit was used exclusively in the experiments described here. Most grit particles in this mesh class are between 0.5 and 1.0 mm. In all experiments, grit was expelled from the sand blaster at 517 kPa (75 psi) air pressure, and all plants were placed 300 mm distant from the tip of the blaster's orifice at the time of their exposure to the grit. At that distance and pressure, more than 50% of the grit hit a 70-mm-wide area (data not shown) in the 90-mm-wide pots.

Corn Growth, Grit Exposure, and Selectivity. Plants of a standard 95-d corn hybrid were grown in an identical fashion to those of lambsquarters. Two types of experiments were performed. The first experiment examined tolerance of corn to blasting by grit and was repeated three times. The three repetitions differed primarily in the developmental stage or height of the corn plants at the time of treatment: trial A, 1.6-leaf stage (± 0.02 SE) and 98 mm tall (± 2.3); trial B, 2.7-leaf stage (± 0.02) and 149 mm tall (± 3.4); and trial C, 2.7-leaf stage (± 0.13) and 171 mm tall (± 11.0). Plants were exposed to 0, 1, 2, 3, 4, 5, or 10 blasts of grit. The check treatment received neither blasts of grit nor air because prior experiments showed conclusively that 10 blasts of air alone at 517 kPa had no effect on even cotyledon-stage lambsquarters plants. Each treatment was replicated four times in trials A and B and three times in trial C.

After treatment with the sand blaster, pots were arranged in trays in a randomized complete-block design, and plants were allowed to grow for an additional 7 d. At 1 d after treatment, each plant was visually assessed for injury (0 = no injury; 10 = death). At 7 d after treatment, each plant was assessed for leaf number, measured for height, clipped at the soil surface, and immediately weighed to the nearest milligram.

Corn tolerance to increasing numbers of blasts was examined in several ways. In all instances, the effect of trials (experimental repetitions) was tested first via ANOVA, and if no interactions with treatments were detected, data were aggregated across trials. Injury data were normalized and arcsine transformed before analysis. Not only were final heights, growth stages, and weights analyzed but also changes between initial (before treatment) and final heights and growth stages were examined.

Theoretically, a dose–response curve fit through a log-logistic equation would be a preferred approach for analyzing these data, as is the case with herbicides that may vary continuously in terms of concentration (Seefeldt et al. 1995). However, in the current case, blasts of grit are discrete units rather than a continuous variable (sensu herbicide rate). Thus, these data were deemed inappropriate to perform log-logistic analysis. Instead, treatment means and standard errors were calculated and plotted. ANOVA was performed merely to underscore seemingly obvious differences between the check and treatments involving one or two blasts.

The second experiment specifically examined selectivity of control by grit. Corn and lambsquarters plants were grown together in the same pots and under the same conditions as described above. A weed plant was never farther than 50 mm away from its associated corn plant. At the time of treatment, the blasting unit was aimed at the weed plant (300 mm distant, 45° angle), but the corn plant, especially its base, invariably was exposed simultaneously to the grit, which was expelled at 517 kPa air pressure from the sand blaster. Each treated pot was exposed to as many blasts as required to obliterate the lambsquarters plant, which required from one to five blasts. At this time of treatment, the weeds ranged from the cotyledon to the four-leaf stage (12 to 45 mm tall), and the associated corn ranged from the 0.8- to 3.7-leaf stage (30 to 250 mm tall). Four of the pots in each trial served as a nontreated check. At 7 d after treatment, all plants were scored for developmental stage, measured for height, clipped at the soil surface, and immediately weighed to the nearest milligram. Two trials were conducted: the first, on May 21, 2008, using 12 pots (each containing a corn and weed plant), and the second, on June 1, 2008, using 18 pots.

Analyses of selectivity involved *t* tests, which were used to compare control plants and treated plants for final fresh weights, heights, and growth stages, as well as changes

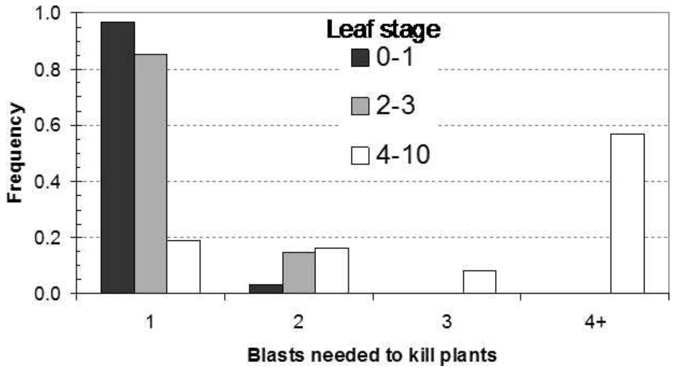

Figure 2. Frequency at which individually potted lambsquarters plants were killed by one, two, three, and four or more, split-second blasts of corn cob grit expelled from a sand blaster at 517 kPa pressure. Lambsquarters plants at time of treatment were at differing stages of growth: (1) cotyledon to one true-leaf stage, (2) two to three true-leaf stage, and (3) 4 to 10 true-leaf stage. Histograms represent the averages of two trials; between which, results were consistent for the cotyledon to one true leaf and two to three true-leaf stages but highly heterogeneous for the 4 to 10 true-leaf stages.

between initial and final heights and growth stages for control plants and treated plants. The *t* tests were also used to show differences in growth of nontreated lambsquarters plants before and after treatments to highlight the utility of eliminating weeds with a selective agent.

Results and Discussion

Frequencies of Weed Kill. Frequency distributions for the number of blasts required to kill lambsquarters plants at the zero- to one- and two- to three-leaf stages did not differ between experiments (K–S statistics ≤ 0.04; $P > 0.99$), allowing these data to be combined (Figure 2). Approximately 97% of zero to one leaf-stage plants were killed by a single blast of grit and all remaining plants by two blasts. Similarly, 85% of the two to three leaf-stage plants were killed by one grit blast and all remaining plants by two blasts.

Frequency distributions of plants at the 4- to 10-leaf stages varied between experiments (K–S statistic $= 0.56$; $P < 0.01$). Percentages of plants killed after one, two, three, and four or more blasts were 4, 15, 8, and 73% in trial A, and 55, 18, 9, and 18% in trial B, respectively. These values were averaged across trials merely for ease of presentation and comparison with results from the zero to one and two to three leaf-stage plants in Figure 1. Whether viewed separately or as averages, results for the 4 to 10 leaf-stage weeds in both trials suggest that control by blasting may not be practical. The reason for this suggestion is that when more than two blasts are required to kill a plant, the mass of grit expelled from the blasting unit increases to what likely is an impractical level on a unit–area basis (data not shown).

In summary, frequencies of plants controlled by blasting confirm that the method is feasible for young plants but much less so for older weeds. The next issue is whether crop plants can tolerate the one or two blasts typically needed to kill young weeds.

Crop Injury. Corn plant injury from differing numbers of blasts of grit did not vary by trial, and therefore, data were combined across trials. Corn injury increased with numbers of blasts of grit (Table 1), but the minor injury resulting from a single blast of grit did not differ from untreated plants ($P > 0.05$). Heights, height changes, leaf stages, and fresh weights of plants 1 wk after treatment differed among trials, but there were no trial by treatment interactions. Consequently, data for each variable was combined across trials. Plant height was not affected by a single blast of grit, but it was reduced appreciably by two or more blasts. However, the change in plant height during 7 d after treatment was reduced by a single blast of grit compared with control plants. In other words, a single blast of grit aimed directly at corn plants did not affect the overall plant height of corn, but it did lessen the height growth rate, at least temporarily, probably because of minor shredding of leaves and accompanying loss of photosynthetic surface area. Additional blasts of grit caused substantially greater amounts of damage.

Leaf stage was not affected by any number of blasts, despite the plants being appreciably injured by four or more blasts. The growing points of these corn plants presumably were protected sufficiently by the soil and the thick culms that the plants survived and continued to develop leaves even after 10 blasts of grit.

Fresh weight was a more sensitive indicator of corn response to grit blasts. A single blast of grit did not decrease fresh weight ($P = 0.07$), but two or more blasts

Table 1. Effects of 0 to 10 blasts of corn-cob grit on corn plants in terms of visual injury 1 d after treatment and final height, change in height (*final height − initial height*), leaf stage, and fresh weight 7 d after treatment. Values are means (± SE) of three separate trials, with three to four replications per trial. Bolded values do not differ from controls (zero blasts) at $P < 0.05$, except for fresh weight where $P = 0.07$.

Blasts	Injury	Height	Δ Height	Leaf stage	Fresh weight
	Scale of 0 to 10	mm		No./plant	g
0	0 ± 0	212 ± 20.4	80 ± 10.1	3.3 ± 0.16	1.99 ± 0.304
1	**1.2** ± 0.14	**205** ± 23.0	55 ± 6.5	**3.4** ± 0.19	**1.95** ± 0.624
2	4.0 ± 0.44	166 ± 10.9	35 ± 7.1	**3.2** ± 0.16	1.21 ± 0.190
3	5.0 ± 0.58	160 ± 12.3	24 ± 9.3	**3.4** ± 0.20	1.20 ± 0.175
4	6.2 ± 0.40	155 ± 16.6	25 ± 9.4	**3.3** ± 0.22	1.09 ± 0.220
5	6.3 ± 0.47	144 ± 13.0	8 ± 9.7	**3.3** ± 0.22	1.10 ± 0.172
10	8.3 ± 0.25	105 ± 11.3	−22 ± 8.3	**3.2** ± 0.18	0.87 ± 0.186

reduced fresh weight by $\geq 39\%$ at 7 d after treatment. Because none of these plants died, each would have been expected to resume growth. The extent of long-term recovery from damage by grit blasting, however, is not known at this time.

In summary, directly blasting corn plants with grit caused damage, but the extent of corn damage from a single blast of grit was minimal. The next issue is the extent of corn injury when grit is aimed directly at co-occurring small weeds, regardless of the number of blasts needed to eliminate those weeds.

Selective Weed Control with a Growing Crop Plant. At the time of treatment, weeds ranged in size from the cotyledon to the four-leaf stage and, consequently, up to five blasts of grit were required to kill some weed plants. Frequencies of one, two, three, four, and five blasts needed to kills weeds were, respectively, 0.44, 0.22, 0.22, 0, and 0.11 in trial A, and 0.93, 0.07, 0, 0, and 0 in trial B. The expelled grit from the blasting unit was aimed at the weeds, rather than specifically aimed at the crop (as in the above experiment), and consequently, little detectable crop damage occurred (injury ratings were ≤ 1), regardless of blast frequency, but all weeds were eliminated. Because corn plants ranged considerably in size at the time of treatment (30 to 102 mm), the change in corn height before and 7 d after treatment was chosen as a very sensitive indicator of possible damage by the blasting treatments (as documented in Table 1), and each trial was analyzed separately. In trial A, changes in height did not differ ($P > 0.05$) between control plants (69 $\pm$ 3.8 mm) and treated plants (74 $\pm$ 5.9 mm); and the same held true for trial B (88 $\pm$ 14.5 mm for controls and 101 $\pm$ 9.2 mm for treated plants). Furthermore, all of these values were similar to the values for control plants from the previous experiment (Table 1), which suggests that specifically blasting weeds with grit causes little damage to co-occurring corn plants. During the 7 d between treatment and measurement, lambsquarters in the control pots grew an average of 8 mm ($\pm$ 0.7 mm) and developed two ($\pm$ 0.0) additional leaves in trial A and 13 mm ($\pm$ 1.8 mm) and three ($\pm$ 0.3) additional leaves in trial B. No weeds survived the blasting treatments.

In summary, weeds were eliminated, and the corn plants were not damaged enough to reduce their rates of growth when grit from a blasting unit was aimed directly at weeds growing proximally to the corn. Weeds not blasted continued to grow and develop.

The three sets of experiments described here provide preliminary evidence that grit derived from crop residues, like corn cobs, can be used to control small weed plants when the grit is delivered by a single, split-second blast from a sand blaster pressurized at about 500 kPa. An identical treatment aimed directly at corn plants caused minimal damage. When corn and weed plants were grown together and the grit was aimed directly at the weeds and not the corn, weeds were killed, and the crop was not damaged. Results from initial greenhouse pot experiments should never be interpreted too optimistically. Nevertheless, these results point to the possible utility of air-propelled, agriculturally derived grit for selective POST control of weeds in no-till row crops.

Sources of Materials

[1] Statistix 8, Analytical Software, Inc., P.O. Box 12185, Tallahassee, FL 32317.

[2] Cyclone Manufacturing, P.O. Box 815, Dowagiac, MI 49047.

Names of manufacturers are solely for descriptive purposes. USDA-ARS does not endorse products of one manufacturer over another.

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